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ABSTRACT

Several large scale laser applications require diode pumps for high efficiency and average power, but are sensitive to diode performance-cost tradeoffs. This paper describes approaches for addressing these issues in pulsed laser systems, using an example of inertial fusion energy drivers.

1. INTRODUCTION

Interest in high energy, pulsed laser systems has recently expanded, to address applications in areas such as scientific exploration and inertial fusion energy (IFE).[e.g.; 1- 2] To achieve high beam quality with pulse durations below 20 ns, these lasers typically utilize optically pumped gain media. When such systems must operate at high repetition rates (above 5 Hz) or with high efficiency (>10%), semiconductor laser diodes are used as pumps because of their high brightness, high wallplug efficiency, and narrow emission spectrum. .[2-6] Because pump power levels >100 kW are required for the lasers of interest, the diode arrays contribute significantly to overall system cost, and design strategies must be implemented to minimize these costs. This paper discusses the performance tradeoffs of such approaches, methodologies for quantitatively assessing their impact on system costs, and the conclusions resulting from these analyses.

2. PUMP DIODE MINIMIZATION STRATEGIES

Current pump costs are dominated by packaging and assembly costs that scale with chip count and depend weakly on chip output power. At the component level, their performance/cost ratio optimizes at the maximum feasible chip power (typically limited by reliability considerations), which can be evaluated using a "cost per Watt" metric. Thus, component optimization strategies focus on increasing the power output per diode chip and minimizing the manufacturing cost. At the system level, the strategies focus on minimizing the required pump power and structuring requirements to minimize production costs. Fig. 1 depicts these options their interplay in detail.

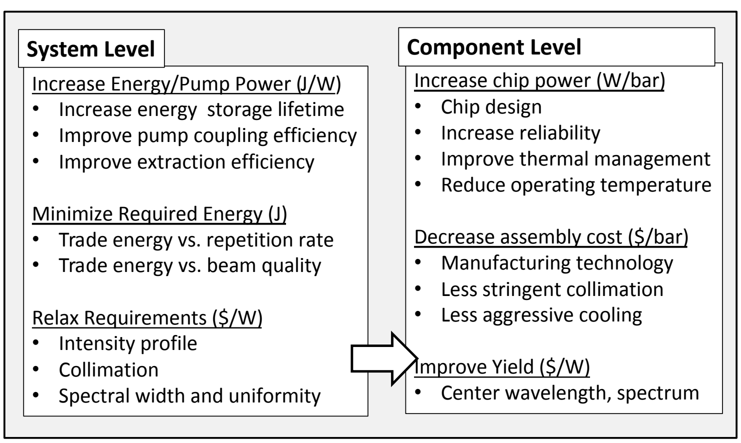

Figure 1: Pump Cost Optimization for Diode-pumped, Pulsed Laser Systems

System-level design choices for the gain medium and its geometry can impact pump costs by simplifying the requirements. Gain media with broad spectral absorption minimize diode spectral requirements and thus improve yield, and appropriate optical designs for delivering pump light to the gain medium and minimize requirements on and costs due to diode collimation.[2] The total required pump power can be reduced by using gain media with longer energy storage lifetimes.[4-6] Component-level strategies include increasing the power per diode chip,[2, 7] simplifying the package design,[8] and operation at cryogenic temperatures.[9]

To illustrate of pump performance/cost optimization complexities, we consider strategies based on increased diode chip power. Recent reports of edge-emitting chips emitting ~1 kW from a "1 cm bar", [7,10] represent a roughly twofold increase in chip power, suggesting the feasibility of a twofold cost reduction. High power operation, however, can degrade pump coupling efficiency due to increases in pump spectral width. These increases result from both the "thermal chirp" during a QCW pump pulse and the increased spectral nonuniformity at higher average heat loads incurred due to device-to-device variations in efficiency and cooling. Furthermore, high power operation above ~500 W/bar may reduce EO efficiency, increasing system costs associated with the electronic drivers for the pumps. While these effects can be mitigated by distributing diode heat and current over larger chip areas,[7] the increased die size impacts the cost of both the bare die and packaging materials. Similarly, mitigation strategies based on aggressive diode cooling or low operating temperatures [9,10] can impact cooling subsystem costs.[12] Alternatively, chip-level designs that improve EO efficiency can mitigate these tradeoffs with less impact on overall system costs. For example, use of multiple, stacked *pn* junctions can significantly increase the chip power with lower efficiency penalties due to I^2R ohmic losses.[11] In general weaker scaling of pump costs than anticipated from a simple "cost per Watt" model occurs due to such factors, when impacts on other system costs are included.

Given the complex dependencies described above, effective performance/cost optimization requires cost models that capture the impact of different design choices on the laser diodes themselves as well as the impact on their supporting utilities, so that system-level assessments can quantitatively compare different options. Diode laser costs can be quantified with process-based cost modeling,[13] to obtain quantitative comparisons of different device designs and manufacturing processes, and to estimate cost scaling with production rates and volumes. Recent application of this approach to the diode pumps required for IFE drivers has provided useful insight into the path forward for these lasers.[14]

3. CONCLUSIONS

There exists a complex interplay of pump diode costs with system-driven requirements and the system utility costs. To effectively optimize pump diode performance/cost tradeoffs, quantitative cost models are required and the optimization must be performed at a system level that includes the laser diodes themselves as well as their supporting utilities. Diode cost estimations for this purpose can be performed using process-based cost models. Additional examples and conclusions will be presented at the conference.

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